

Polarization Reconfigurable MEMS-CPW Antenna for mm-wave Applications

J. Balcells[#], Y. Damgaci⁺, B. A. Cetiner⁺, J. Romeu[#], L. Jofre[#]

[#]*Departament de Teoria del Senyal i Comunicacions (TSC), Universitat Politècnica de Catalunya (UPC),*

Jordi Girona 1-3, 08034, Barcelona, Spain

(balcells,jofre)@tsc.upc.edu

⁺*Department of Electrical and Computer Engineering (ECE), Utah State University,*

4120 Old Main Hill, Logan, UT 84322, USA.

bedri@engineering.usu.edu

Abstract — This letter presents a polarization reconfigurable MEMS-integrated coplanar patch antenna for mm-wave applications. The polarization of the field radiated by this reconfigurable antenna can be configured into right-handed circular polarization (RHCP), left-handed circular polarization (LHCP) or linear polarization (LP). This is accomplished by the activation/deactivation of RF-MEMS switches. The consistency of the simulated results was successfully checked with measurements.

I. INTRODUCTION

Recently, there has been growing interest for millimeter-wave Wireless Personal Area Networks (WPANs) systems operating around 60 GHz. The IEEE 802.15.3c international standard is providing regulations for the short-range data networks (<10m) with 7 GHz bandwidth and data rate between 2 Gbps and 3 Gbps [1].

Propagation characteristics at millimeter-wave frequencies make necessary the development of high efficiency communications systems. The system overall performance is strongly dependent on the antenna structure, facing challenges such as high gain and adaptable antenna systems [2]. Because of high path loss at V-band frequencies, WPANs should employ high-gain antennas. In addition, the use of directive antennas reduces multipath contributions by limiting the angles from which radiation is emitted and captured. The unknown positions of the terminals make steerable beam antennas good candidate to be used. All these characteristics lead to consider phased array antennas as the most appropriate radiating devices. The polarization of the antenna also influences the link. The unknown orientation of the terminals makes antennas with polarization diversity attractive since they allow the link to operate independently to the antenna orientation, improving the performance of the system. In antenna arrays, polarization diversity may be achieved by using individual elements with polarization reconfigurability.

For the last several years, patch antennas [3], quarter-wave patch antennas [4], Yagi-Uda antennas [5], loop antennas [6] or slot antennas [7], have been proposed as possible WPANs antennas. Characteristics such as low profile, light weight, planar structure, low-cost fabrication and integration on the

package have been targeted. Because of its wide bandwidth and reduced losses, the most common structure used at millimeter-waves is co-planar waveguide (CPW).

The purpose of this paper is to present an omnidirectional polarization reconfigurable antenna using nano/micro-electromechanical system (N/MEMS) switches.

II. ANTENNA DESIGN AND SIMULATION

The proposed structure for a millimeter-wave polarization reconfigurable antenna consists of a square coplanar patch antenna printed on a very thin (200 μ m) Synthetic Quartz Glass substrate. The substrate's dielectric properties at 60 GHz are $\epsilon_r=3.9$ and $\tan\delta=7\times10^{-4}$. The structure has been modeled and optimized with the commercial software Ansoft HFSS [8].

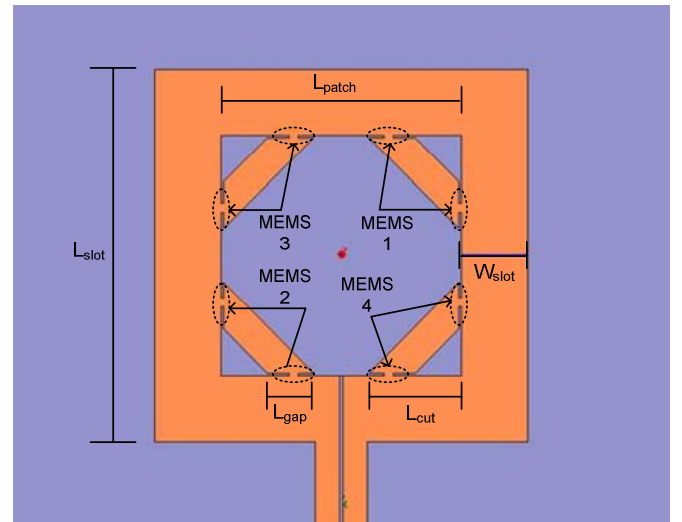


Fig. 1 Layout of the antenna

The antenna proposed structure is shown in Fig. 1. The metal part is drawn in grey and the substrate layer is in orange. To generate circular polarization from a square patch, two pairs of opposite corners are cut, providing the necessary perturbation to obtain the two required orthogonal near-

degenerated resonant modes. The resulting corner-truncated square coplanar patch antenna has four small parasitic conductors of triangular shape that are connected to the patch by recently developed reduced size RF-MEMS switches [9]. The polarization of the radiated field by this reconfigurable antenna can be configured into LP, RHCP or LHCP.

A. Linear Polarization (LP)

The first configuration under study has been the linearly polarized antenna. The length of the slot L_{slot} has been designed to be slightly larger than a quarter wavelength, leading the square-slot inner perimeter to be equal to one guided wavelength. The resulting field distribution at 60 GHz shown in Fig. 2 illustrates how the patch mode TM₀₁₀ is induced. The length of the square patch L_{patch} and the width of the slot W_{slot} are designed to obtain good impedance matching.

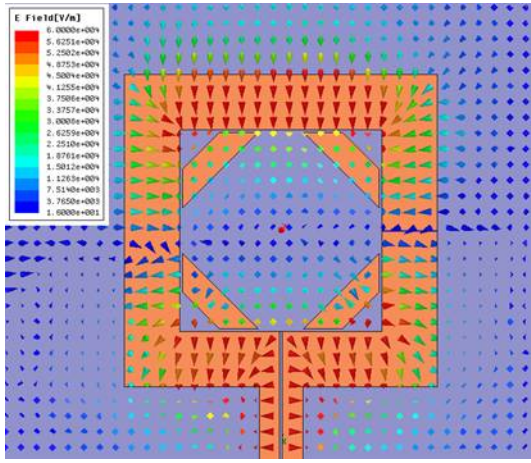


Fig. 2 Field distribution for linear polarization

The patch feeding has been studied, concluding that the inductive feed was the most appropriate to induce the desired patch modes either for linear or circular polarization.

B. Circular Polarization (CP)

Circular polarization is obtained by inducing two orthogonal modes with equal amplitude and in-phase quadrature. In a single-point feed patch, this can be accomplished by perturbing the patch at appropriate locations with respect to the feed [10]. A typical method to generate CP is to truncate the corner of the patch. With the appropriate amount of perturbation, the two modes will have the same amplitude and a phase difference of 90° at the operating frequency. Depending which corners are truncated, the CP resulting will be right-handed (RHCP) or left-handed (LHCP). Fig. 3 shows the resulting field distribution at 60 GHz for LHCP configuration. It can be seen how the patch mode TM₁₁₀ is induced. The amount of perturbation L_{cut} and L_{gap} necessary to obtain a good CP have been obtained by simulation.

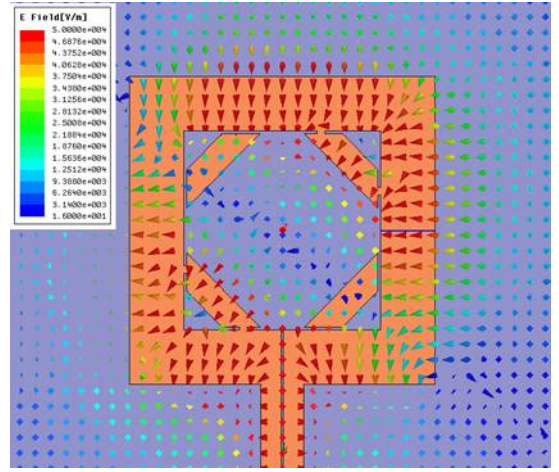


Fig. 3 Field distribution for left-handed circular polarization

C. N/MEMS design

At high frequencies, the behavior of the N/MEMS has to be analyzed, focusing on the insertion loss and switching speed. The nanofabrication of this MEMS integrated antenna prototype on a quartz substrate, which will be used to generate experimental results, is currently under progress. We have already designed, fabricated and characterized single- and double-arm RF-MEMS switches [9] with various dimension: cantilever length ($L = 5 - 60 \mu\text{m}$) and width ($W = 2 - 40 \mu\text{m}$), i.e., $\sim 10 - 100$ times smaller in lateral dimensions than standard MEMS switches. The typical dimensions of the MEMS switches, which are currently being integrated into the geometry of the proposed WPAN antenna designs, are $L = 30 \mu\text{m}$ and $W = 10 \mu\text{m}$ as shown in Fig. 4. Small dimensions of MEMS are needed to achieve fast switching speed and low actuation voltage ($\sim 10\text{V}$). Moreover, the small size of the antenna at 60 GHz range is compatible for integration with small size MEMS switches.

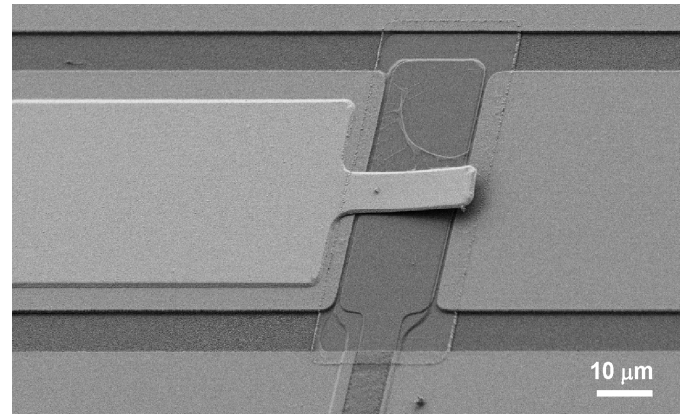


Fig. 4 Photograph of the complete Single-arm RF-MEMS switch [9]

D. Reconfigurable Antenna

The linear and circular polarization designs have been combined to obtain the final reconfigurable antenna design presented in Fig. 1. The antenna parameters values in guided wavelengths are summarized in Table I.

TABLE I
ANTENNA PARAMETERS

Parameters	Value (in λ_g)
L_{slot}	0.33
L_{patch}	0.21
W_{slot}	0.05
L_{cut}	0.08
L_{gap}	0.04

The reconfigurability in polarization is accomplished by the activation/deactivation of the RF-MEMS switches as presented in Table II. This technique is well known and has been widely used in practical designs in other frequencies and structures [11].

TABLE II
RF-MEMS SWITCH CONFIGURATION

	MEMS 1	MEMS 2	MEMS 3	MEMS 4
LP	ON	ON	ON	ON
	OFF	OFF	OFF	OFF
RHCP	ON	ON	OFF	OFF
LHCP	OFF	OFF	ON	ON

Concerning the impedance matching of the antenna, two CPW lambda quarter transformers have been used. The use of two transformers is to minimize the effects of the line while adapting the high impedance of the patch. The transmission lines were designed taking into account the manufacturing limitations, the effects of the line and considering the dimensions of a standard 150 μm pitch ground-signal-ground (GSG) probe.

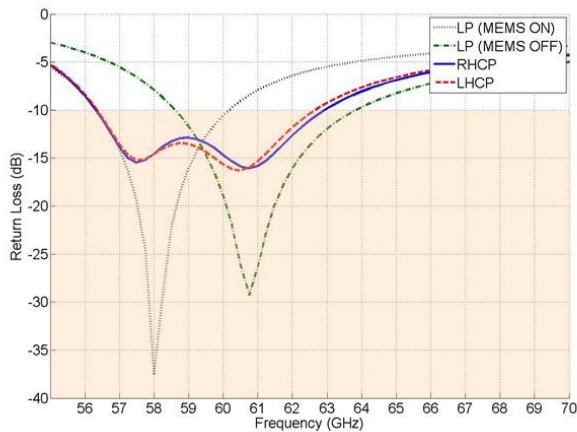


Fig. 5 Antenna Return Loss (Simulated)

In Fig. 5, the simulated return loss of the antenna is presented for the four possible configurations. The antenna exhibits an impedance bandwidth of 11% relative to -10 dB return loss when configured with CP. When configured with LP, the bandwidth is 9%, considerably higher than the typical 5% of the microstrip patches.

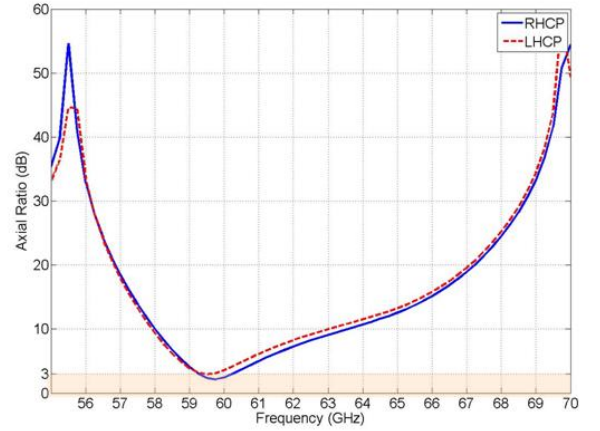


Fig. 6 Axial Ratio along frequency (Simulated)

Fig. 6 illustrates the antenna Axial Ratio for both circular polarizations, left- and right-handed in the maximum radiation direction. The simulated -3dB axial ratio bandwidth is 1.6%.

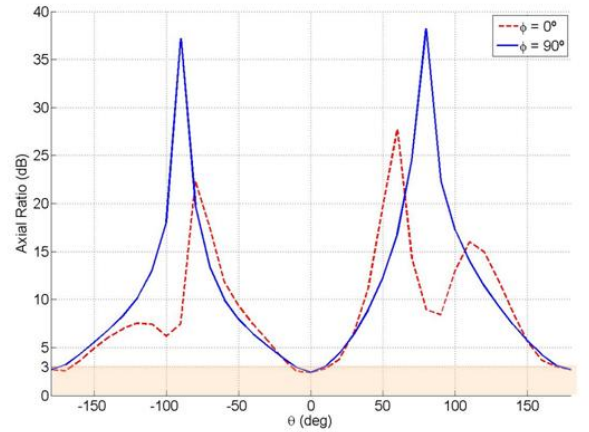


Fig. 7 Axial Ratio for E- and H- plane (Simulated)

In Fig. 7 can be seen the simulated axial ratio in E- and H- plane at center frequency with LHCP configuration. A -3dB axial ratio beamwidth of 20° is observed.

III. ANTENNA FABRICATION

The antenna with the dimensions and features described above is under process of fabrication. In the meanwhile, a scaled (factor 4) antenna has been simulated, fabricated and tested at Ku-band. The dielectric used in this design has been Rogers 4003C with a relative constant of $\epsilon_r=3.55$ and a thickness of 0.8 mm. The MEMS switches have been replaced by a short circuit when ON and by an open circuit when OFF.

Four different antennas with the four different configurations have been built and tested as can be seen in Fig. 8.

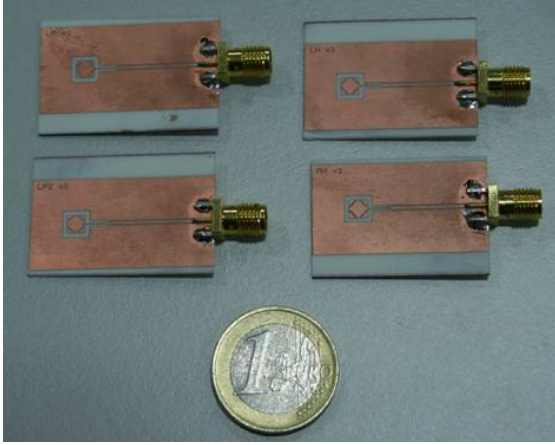


Fig. 8 Four different fabricated Ku-band Antennas

Fig. 9 illustrates the measured return loss for the four different antenna configurations. The results are slightly shifted to lower frequencies due to fabrication tolerances. Excluding the LP solution with all MEMS OFF, the -10 dB Return Loss bandwidth is at least 8%.

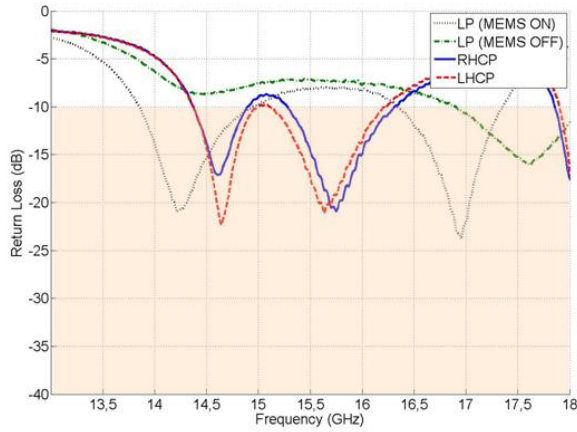


Fig. 9 Return Loss

The Electric field components E_x and E_y have been measured in the anechoic chamber with a E-plane sectoral Horn antenna as probe. From the obtained results, the axial ratio has been computed as indicated in [12]. Fig. 10 illustrates the axial ratio along frequency for the four antennas. LP configurations show a high axial ratio (>20 dB) while the axial ratio for LHCP and RHCP is low. The differences observed between the two circular polarizations measurement are due to fabrication tolerances. With the LHCP configuration, the -3dB axial ratio bandwidth obtained is 1.7%.

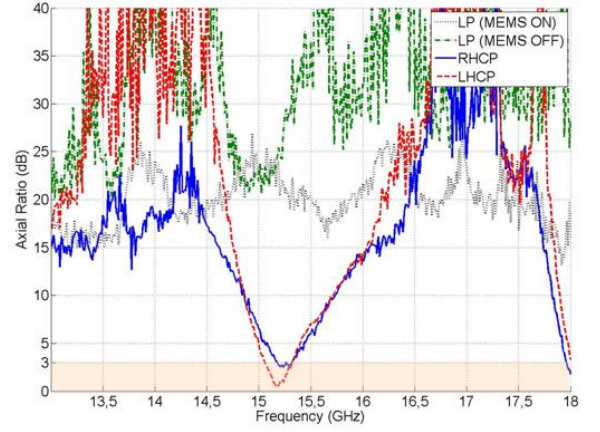


Fig. 10 Axial Ratio along frequency

In Fig. 11 the axial ration in E- and H-plane at center frequency with LHCP configuration is presented. The -3dB axial ratio beamwidth is at least 20° , as observed.

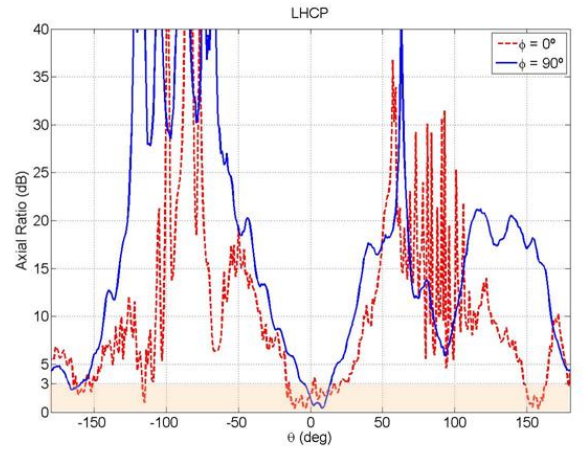


Fig. 11 Axial Ratio for E- and H- plane

IV. CONCLUSIONS

A planar omnidirectional polarization reconfigurable antenna using nano/micro-electromechanical system (N/MEMS) switches at 60 GHz band has been presented. The antenna exhibits an impedance bandwidth relative to -10 dB return loss of 10 %. When configured in CP, the -3dB axial ratio bandwidth obtained is 1.6%. Due to manufacturing limitations, a scaled antenna at Ku-band has been fabricated with a slightly different substrate. Good agreements between simulation and measurements are observed. These good measurements results have to be corroborated at 60 GHz. The reconfigurability of the polarization makes the antenna presented a good candidate for those applications requiring polarization diversity in the 60 GHz band.

ACKNOWLEDGMENT

This work was supported in part by the Spanish Interministerial Commission on Science and Technology (CICYT) under projects TEC2007-66698-C04-01/TCM and CONSOLIDER CSD2008-00068, and by the "Agència de Gestió d'Ajuts Universitaris i de Recerca" through the FIR fellowship program, and by the project "Tri-band planar antennas for VSAT Satellite Applications." from INDRA.

REFERENCES

- [1] R. Fisher, "60 GHz WPAN Standardization within IEEE 802.15.3c", International Symposium on Signals, Systems and Electronics, 2007. ISSSE '07, pp.103 – 105, July 30 -Aug. 2
- [2] R. C. Daniels and R. W. Heath Jr., "60 GHz Wireless Communications: Emerging Requirements and Design Recommendations". *IEEE Vehicular Technology Magazine*, September 2007.
- [3] S. Ranvier, S. Dudorov, M. Kyrö, C. Luxey, C. Icheln, R. Staraj and P. Vainikainen, "Low Cost Planar Omnidirectional Antenna for Mm-Wave Applications", *IEEE Antennas and Wireless Propagation Letters*, Volume 7, 2008 Page(s): 521 – 523.
- [4] S. Seok, N. Rolland, P.-A. Rolland, "A 60 GHz quarter-wave patch antenna based on BCB polymer", *IEEE Antennas and Propagation Society International Symposium*, AP-S 2008. 5-11 July 2008.
- [5] A. Boe, M. Fryziel, N. Deparis, C. Loyez, N. Rolland and P.-A. Rolland, "Smart antenna based on RF MEMS switches and printed Yagi-Uda antennas for 60 GHz adhoc WPAN", *36th European Microwave Conference*, 2006. 10-15 Sept. 2006 Page(s):310 – 313
- [6] D. Liu, "Circularly Polarized Antenna Structures for 60 GHz Package Applications", *IEEE Antennas and Propagation Society International Symposium*, 2009. APSURSI '09. 1-5 June
- [7] F. Ohnimus, I. Ndip, S. Guttowski and H. Reichl, "An efficient and broadband slot antenna for 60 GHz wireless applications", *Electrical Design of Advanced Packaging and Systems Symposium*, EDAPS 2008. 10-12 Dec. Page(s):69 – 72
- [8] (2009) The Ansoft Electronic Design Products website. [Online]. Available: <http://www.ansoft.com/products/hf/hfss/>
- [9] N. Biyikli, Y. Damgaci, and B. A. Cetiner, "A low-voltage small-size double-arm MEMS actuator", *Electron. Lett.*, 26 March 2009, Volume 45, Issue 7, p.354–356
- [10] R. Garg, P. Bhartia, I. Bahl, A. Ittipiboon, "Microstrip Antenna Design Handbook", *Microstrip Antenna Design Handbook*, Artech House Inc., Boston 2001
- [11] Y. J. Sung, T. U. Jang and Y.-S. Kim, "A Reconfigurable Microstrip Antenna for Switchable Polarization", *IEEE Microwave and Wireless Components Letters*, vol.14, No. 11, November 2004.
- [12] C. A. Balanis, *Modern Antenna Handbook*, Wiley-Interscience, 2008